# INCIDENCE OF NON-CONTACT ANTERIOR CRUCIATE LIGAMENT INJURIES IN A HYPERPRONATED ATHLETIC POPULATION

by

Jaclyn Beth Arduini

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# STATEMENT OF THESIS APPROVAL

The thesis of **Jaclyn Beth Arduini**

has been approved by the following supervisory committee members:

| | | |
|---|---|---|
| **Charlie Hicks-Little** | , Chair | **March 11, 2016**<br>Date Approved |
| **David H. Perrin** | , Member | **March 11, 2016**<br>Date Approved |
| **Christopher G. Jackson** | , Member | **March 7, 2016**<br>Date Approved |

and by **Janet M. Shaw** , Chair/Dean of

the Department/College/School of **Exercise and Sport Science**

and by David B. Kieda, Dean of The Graduate School.

## ABSTRACT


Hyperpronation has been shown to cause increased internal tibial rotation which, when prolonged, is thought to place increased stress on the Anterior Cruciate Ligament (ACL) and lead to a higher incidence of non-contact ACL injuries in sports. To date, no research has attempted to examine the relationship between hyperpronation and ACL injuries in a longitudinal model, although strong associations have been found in cross-sectional studies involving injured subjects. The cross-sectional data are strong enough to suggest that individuals with a hyperpronated foot will have a significantly greater number of ACL injuries.

The purpose of this research was to complete a prospective cohort study examining the relationship between non-contact ACL injuries and hyperpronation and to determine the incidence rate of such injuries. It was hypothesized that the hyperpronation group would sustain more non-contact ACL injuries than the control group.

Participants consisted of 141 NCAA Division I athletes among nine different sports. Out of the eligible participants, 125 met the inclusion criteria, and were separated into either hyperpronator (≥9mm) or control ( <9mm) based on their navicular drop measurement. Measurements were taken prior to the start of the competitive season. Athlete tracking was completed over the course of 10 months by the supervising athletic trainer and principal investigator, whereby all non-contact ACL injuries were to be recorded.

The mean navicular drop overall with all subjects combined ($n=192$) was $9.62 \pm 4.14$mm. When separated by group, the HP group ($n=109$) mean navicular drop was $12.16 \pm 3.38$mm compared to $6.16 \pm 1.88$mm in the control group ($n=83$). A two-way ANOVA was conducted to examine the effect of group and gender on the navicular drop. A statistically significant main effect for group, $F(2,186) = 207.42$, $p<.001$ was identified, but there were no significant gender or gender by group interactions ($p \geq 0.05$). No non-contact ACL tears recorded. While no non-contact ACL injuries were noted, navicular drop data in the HP group are similar to values found in previous research. Further study over a longer injury tracking timeframe needs to be conducted to determine if hyperpronation can be classified as a predictor variable for non-contact ACL injuries.

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# INTRODUCTION

Anterior Cruciate Ligament (ACL) injuries are common in both general and athletic populations.[1] Data from the National Collegiate Athletic Association Injury Surveillance System (NCAAISS) shows that for 15 different sports over a 16-year period from 1989 to 2004, 4800 ACL injuries were reported.[2] Of these, 36.8% were non-contact injuries that occurred in games, while 17.7% were non-contact injuries that occurred in practices.[2] When looking specifically at basketball, 80% of ACL injuries were non-contact.[3] Similarly, in soccer, 48% of ACL injuries in men and 63% in women were also due to non-contact mechanisms.[3] In a study examining the general population by Gianotti et al. (2009), 81% of all ACL injuries required surgery (ACLS) and of these, 58% were defined as non-contact injuries.[1] A non-contact mechanism of injury is defined as a force being applied to the knee at the time of injury that does not involve any extrinsic contact from another player, object, or equipment on the field.[1,4]

Both extrinsic and intrinsic factors contribute to the acquisition of an ACL injury. Various studies have found relationships between extrinsic factors such as weather conditions, footwear, playing surface, and shoe-surface interaction that could cause a non-contact mechanism, but these studies have proved inconclusive due to the wide variety of focus and quality of the research.[4,5,6] Biomechanical intrinsic factors, those found within the individuals themselves, are important to consider because the majority of ACL injuries are non-contact injuries.[3,4,6,7,8,9] When looking at non-contact injury mechanisms, the most common types of mechanisms involve closed kinetic chain movements such as pivoting, changing direction, decelerating, or landing tasks.[4,3,5,10,11,12,13] The positioning of the lower leg is crucial with respect to the stress put on the ACL, specifically the position of the navicular, subtalar joint (STJ) and the rotation of the tibia.[2,10,14] Hyperpronation, by way of navicular drop, in particular is thought to be the largest effector to the kinetic chain and could therefore predispose the ACL to injury.[1,4,7,8,9,11,12,13,14,15]

***Hyperpronation of the Foot***

Hyperpronated feet are defined as having a low or absent medial longitudinal arch (MLA) resulting in pronation at the subtalar joint (STJ).[7,16] The navicular bone is one of the main bones that comprises the MLA and is responsible for maintaining this arch and preventing excessive pronation statically and dynamically.[7,12,16,17] The STJ, comprised of the talus and calcaneus, primarily controls inversion and eversion of the ankle.[8,11,15] In hyperpronation, the navicular bone drops and pulls the talus into plantar flexion, adduction, and slight medial rotation; the calcaneus then compensates by everting in an attempt to maintain STJ congruency which consequently causes STJ inversion, Figure 1.[8,11,17,18]

Clinically, pronation is measured by the amount of navicular drop between non-weight bearing assisted subtalar neutral and normal weight bearing.[7,3,15,13,20] The Brody Technique is a commonly used and widely accepted method to measure navicular drop between STJ neutral and weight bearing and to classify individuals as HP or not.[7,8,9,13,15,17] STJ neutral is the position of maximum congruency between the talus and calcaneus and is also considered the neutral position of the foot.[11] In weight bearing, few individuals maintain this neutrality and it is therefore the change from neutral to weight bearing that must be assessed.[9] The navicular tuberosity is the boney landmark utilized and a measurement of 9mm or more is considered to be excessive, classifying the individual as a hyperpronator.[7,8,9,15] The Brody Technique has been proven to have good inter- and intratester reliability and was chosen as the method for determining foot type for this reason.[18] Navicular drop measurement is further described within the methods section.

Continuing up the kinetic chain, inversion at the STJ forces the tibia into internal rotation because of its strong articulation with the talus at the talocrual joint.[8,9,11,14] It is this internal rotation of the tibia which is thought to cause a preloading effect on the ACL and put it at greater risk for injury.[8,9,11,14] The internal rotation of the tibia increases the stress placed on the ACL because of the arrangement, direction, and insertion of the fibers of the ACL.[9,11] The fibers of the ACL run inferiorly and medially from the posteromedial border of the lateral femoral condyle to the tibial plateau between the tibial spines.[8,17,21] The ACL then works to limit anterior tibial translation, knee hyperextension, and excessive internal tibial rotation and therefore is loaded in a position of internal tibial rotation.[8,9,17]

### *Hyperpronation and Stance Phase*

Changes in the positioning of the foot and lower leg not only occur in static weight bearing, standing but in gait as well. [7,8] During gait, the foot initially contacts the ground at heel strike with the STJ in slight supination and the knee in full extension. The

ACL is loosest here with only the posteromedial bundle being taut during this phase.[8] During the stance phase of gait as the foot is in full contact with the ground, the MLA and STJ pronate and force the tibia into internal rotation; the knee flexes here to approximately 20° with the ACL becoming heavily loaded.[8,9] As the heel begins to lift off, the STJ begins to supinate and will continue to do this through toe off.[8] Supination at the STJ allows the tibia to externally rotate into a more neutral position and the ACL to unload as muscles of the thigh take over and the knee extends.[8]

In individuals with hyperpronation, the STJ remains in pronation throughout stance phase and into toe off, therefore inhibiting the external rotation of the tibia.[8,9] Although the knee will still go through the same amount of flexion and extension as those without hyperpronation, the ACL will remain under more stress since the tibia will be in internal rotation.[8,9,11] As with static loading, it is this obligatory internal rotation of the tibia from hyperpronation that induces a preloading effect which further predisposes the ACL to injury.[8,9,11] The vast majority of non-contact injury mechanisms occur with the foot planted so it is relevant to look at hyperpronation in normal weight bearing.[4,3,5,8,9,13,20,22,23]

### ***Non-contact ACL Injuries and Hyperpronation***

In a review of non-contact ACL injuries in soccer players, Alentorn-Geli et al. (2009) state that overall, it is accepted that most ACL injuries are non-contact in nature in both men’s and women’s sports.[4] They, along with others, agree that the common mechanisms of injury involve knee valgus with internal rotation of the tibia and an anterior translation force at the knee.[4,7,8,9,13,14,20,24] The theory that links hyperpronation with increased tibial rotation has been long standing, with Coplan measuring the amount of passive tibial rotation in 1989 and finding it to be 5° greater in pronators than non-pronators.[14] Beckett et al. in 1992 compared 50 ACL injured subjects to 50 uninjured subjects and found that although there were no differences in navicular drop scores between those injured in a contact to non-contact mechanism, there was a significant difference in navicular drop scores between those injured and those noninjured.[8] Beckett was one of the first to link prolonged pronation to a preloading of the ACL due to the internal rotation of the tibia.[8]

Woodford-Rogers et al. (1994), Louden et al. (1996), Jenkins (2007), Allen and Glasoe (2000), and Smith (1997) all looked further into the relationship between hyperpronation and ACL injuries. [20,9,24,7,13] Woodford-Rogers et al. sought to determine if clinical measures of calcaneal eversion, navicular drop, and anterior joint laxity could distinguish ACL injured subjects from non-injured subjects when matched for sport, team, and position.[20] While their results were not conclusive, regression analysis revealed that 20% of the differences between the ACL injured and non-injured groups could be attributed to navicular drop and anterior joint laxity.[20] This is significant as it has been postulated that the preloading effect of internal rotation of the tibia loads and could stretch the ACL, leading to increased anterior joint laxity.[7, 8,9,13,24] Smith et al. found similar results in that, although their navicular drop values failed to distinguish the ACL injured group from the uninjured group, they did find that the ACL injured group did have larger navicular drop values.[13] Louden et al. looked at static posture in females in relation to ACL injuries, stating that as static posture was a basis for dynamic posture, the athlete would typically return to or land in this home posture once the neuromuscular system is stressed.[9] They found that STJ position (as measured by navicular drop) was a significant predictor for ACL injury when comparing between the ACL injured and non-injured limb within the same subject.[9] Allen and Glasoe when again measuring navicular drop between ACL injured and uninjured subjects found a significantly higher drop in those who had sustained a non-contact ACL injury when compared to healthy subjects.[7]

Jenkins et al. is one of the only researchers to date who has found results contrary to that of the previously mentioned literature. Even though Jenkins did not find a significant difference in the foot structure (as measured by navicular drop) between ACL injured and uninjured subjects, he did note that there was a trend towards a significant difference at $p=.06$ and that this trend needed further analysis.[24] As most past research compares previously injured and ACL repaired subjects with non-injured subjects, there is a certain bias to the data and to the literature. This cross-sectional approach is problematic as there is strong evidence showing that compensations in gait and weight bearing occur with ACL injury and repair.[12,25] Studies looking at injured or repaired ACLs cannot be truly validated as the compensations of the individual from his or her pre-injury state are unknown. [7, 8,9,13,14,20,24]

A prospective study has yet to be completed to determine if a hyperpronated foot is a valid risk factor for non-contact ACL injury. A longitudinal model is needed to determine if there is a relationship that exists prior to injury.

### *Clinical Relevance*

According to a 2007 study by Hootman et al. that reviewed 16 years of the National Collegiate Athletic Association (NCAA) Injury Surveillance System (ISS), ACL injuries are on the rise.[2] Hootman et al. determined that the 5000 ACL injuries that occurred from 1988-1989 to 2003-2004 represent approximately 15% of the total population of actual ACL injuries that occurred, putting the total number of ACL injuries per year at 2000, a number that while large, should not be surprising.[2] Interestingly, although ACL injuries represent only 3% of the total injuries recorded in the study, 88% of them resulted in more than 10 days lost, a significant amount of time for any sport.[2] Since most, if not all, ACL injuries at the NCAA level require surgery, it is important to think beyond that of time lost and to the cost of such injuries.

Gianotti et al. examined at ACL and other knee ligament injuries over a 5-year period in New Zealand.[1] While the study focused on the general population and pulled data from the New Zealand's no-fault injury compensation board, which provides a national registry of injuries, most of the injuries reported were non-contact.[1] Additionally, of the knee injuries reported, 80% were surgical and 65% of those were for ACL repair.[1] The mean cost of pre- and postoperative care including assessment and surgical costs as well as rehabilitation was $11157.35 NZD or $7591.35 USD in 2009 when the study was published.[1] Within the NCAA, costs of this nature are generally paid for by the universities that the athletes attend. If we were to take the data by Hootman et al. and combine it with the cost estimate of Gianotti et al., the amount of money spent per year on ACL injuries in the NCAA is over $15,000,000.[1,2] This pales in comparison to the numbers reported by Boden et al. (2000) who reported that of the 250,000 ACL injuries in the United States each year one third are surgical and cost approximately $17,000 each to repair.[26] This totals $1.5 billion per year and does not include evaluation or rehabilitation costs associated with injury and surgery.[26]

Additionally, Laible and Sherman (2013) estimate that while $100 million is spent in the United States per year on ACL prevention research, this is still less than the total cost placed on society from the injuries themselves, warranting further research to determine further prevention methods.[27]

Intervention strategies for ACL prevention are plentiful, with the majority focusing on neuromuscular training as this has been found effective in past research.[6] In fact, in a study by Gilchrist et al. in 2008, ACL injuries were 41% lower over the course a season in the intervention group than in the control group.[6] Additionally, when looking at non-contact injuries specifically, the intervention group had only two ACL injuries compared to 10 in the control group, a decrease of 70%.[6] Clinically, it can be theorized that by strengthening the muscles of the foot and lower leg, one can change the biomechanics of the foot and lower leg both statically and dynamically, essentially giving an individual a new base of support through repetition and training. As this is the basis for any strength and conditioning, rehabilitation or prevention program one only needs to apply it to the foot in order to accomplish similar outcomes. Lynn et al. (2012) did just that in their study of strengthening intrinsic foot musculature and the effect on the MLA, center of pressure, and mediolateral movement in static and dynamic balance tasks.[28] They found that isometric contractions of 5 seconds and a “towel scrunching” exercise completed 100 times a day every day for 4 weeks decreased the mediolateral movement of the foot and helped to center the center of pressure in dynamic tasks.[28] While there was no significant effect on MLA height, it should be noted that the individuals included in the study were “healthy individuals” and while their navicular height was measured in standing, no navicular drop was measured pre- or postintervention so we cannot be certain if there was a change in navicular drop and the amount of pronation of the foot.[28] Clearly, more research needs to investigate  this topic, but if there is a relationship between hyperpronation and non-contact ACL injuries, such research would be warranted as decreasing both the time lost and costs associated with non-contact ACL injuries would be of benefit.

### *Statement of Purpose*

The purpose of this research was to complete a prospective cohort study examining the relationship between non-contact ACL injuries and hyperpronation and to determine the incidence rate of such injuries.  It was hypothesized that the hyperpronation group would have sustain more non-contact ACL injuries than the control group

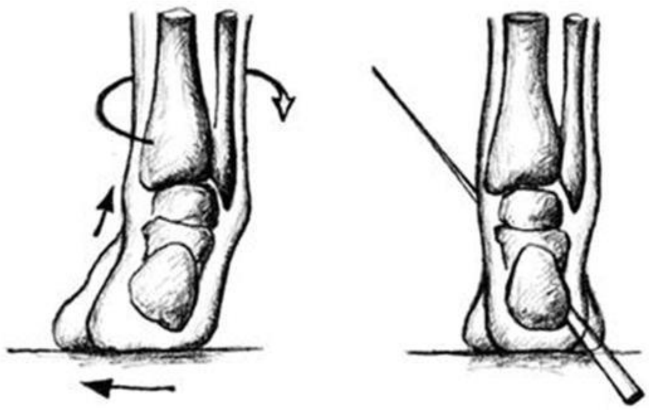

**Figure 1:** Hyperpronation vs. neutral weight bearing. The navicular bone drops, pulls the talus into adduction, and the STJ into eversion, causing the tibia to internally rotate. [19]

# METHODS

### *Subjects*

NCAA Division I athletes from the University of Utah were recruited from various sports based on a convenience sampling method. To be included in the study, the subjects must not have had any prior lower body fractures, lower body surgeries, or lower body injuries within 30 days prior to data collection. The Lower Body Injury Questionnaire (LBIQ) (see Appendix) was utilized by the researcher as well as supervising athletic trainers (staff and graduate assistant athletic trainers) working with each team in order to obtain this information. The subjects were coded for sport, gender, and foot side, thus allowing each foot to be treated as a separate subject.

To be categorized as a hyperpronator (HP) a subject must have had a navicular drop equal to or greater than 9mm, which is consistent with the research.[3,7,9,15] All subjects with a navicular drop of less than 9mm were considered within normal limits and placed in the control group. Both groups were monitored throughout the competitive season (approximately 10 months) which included pre- and postseason events such as training camps, practices, scrimmages, and games.

### *Experimental Protocol/Procedures*

Available NCAA Division I athletes at the University of Utah completed the LBIQ prior to the start of the competitive season. Having completed the questionnaire, subjects were provided an identification (ID) number coded for by sport, gender, and foot side, (i.e. right or left foot), to monitor their status (Figure 2). Codes were combined so that each navicular drop was recorded on an individual blank 3x5 inch flash card and also recorded in Microsoft Excel (2013) to be analyzed later. For example, a soccer player would be coded as 015-9-2-1, stating that the athlete was subject 15, they played soccer (9), they are female (2), and the right foot was being measured (1). Subjects that met the inclusion criteria had their navicular drop(s) measured either at their preseason physical examination, after a strength and conditioning session, or practice prior to the start of the competitive season. The supervising athletic trainer with the respective sports was asked to keep a record of any non-contact ACL injuries, Grade II or greater as defined by Magee (2008) for the duration of the reporting period.[17] At the end of the reporting period, the researcher collected, via email, injury reports for each sport with regards to any non-contact ACL injuries.

***Experimental Measures***

Navicular drop was measured using the technique as described by Brody.[15] The subject was seated barefoot with the knees at approximately 90º while the navicular tuberosity was palpated and marked with a felt marker. The examiner then placed her thumb and index finger on either side of the tibiotalar joint at the depressions formed by the talus at this joint at the ankle. While palpating the right ankle, the thumb is placed anterior to the fibula on the lateral aspect and the index finger is placed just anterior and inferior to the medial malleolus on the medial aspect. The examiner then passively inverted and everted the subjects' ankle, determining when the depressions felt equal bilaterally. This is the neutral position of the foot or subtalar neutral (STN). The foot was then placed on the floor and the subject asked to maintain this position via muscular control as the 3x5 inch card with the athlete's ID number was placed medial to the foot. The height of the navicular tuberosity was then marked on the card. The subject was then asked to stand comfortably, weight bearing equally and normally between both feet. The position of the navicular tuberosity was again marked on the card and the difference between the two positions was measured as the navicular drop of the subject (Figure 3). This procedure was then repeated on the left foot. The navicular drop was measured with a standard ruler in millimeters and recorded both on the card and in Excel for further analysis. Any measurement equal to or greater than 9mm was considered to be excessive and that navicular drop was put into the HP group.[3,15,5,22] Those with navicular drops less than 9mm were included in the control group. Both groups were monitored for non-contact ACL injuries.

***Data Analysis***

Microsoft Excel (2013) and SPSS (IBM, Version 23) were used to analyze the data. Excel (2013) was used to calculate means and standard deviations of the population separated by group, gender, and sport using the *Descriptive Statistics* function. Descriptive statistics are displayed in Table 1. SPSS was used to employ a 2x2 Factorial ANOVA test in order to determine the difference in means between groups (control, HP), genders, and the interaction between group and gender (group × gender). Statistically significant main effects were followed up with independent t-tests. The incidence of non-contact ACL injuries would have been calculated for both the HP and control groups (gender combined and separated) if there had been any non-contact ACL injuries within the data collection timeframe. Statistical significance was set at $p \leq 0.05$.

| Sport | Code | | Side | Code | | Gender | Code |
|---|---|---|---|---|---|---|---|
| Baseball | 1 | | Right | 1 | | Male | 1 |
| Basketball (M) | 2 | | Left | 2 | | Female | 2 |
| Basketball (W) | 3 | | | | | | |
| Cross Country | 4 | | | | | | |
| Football | 5 | | | | | | |
| Golf | 6 | | | | | | |
| Gymnastics | 7 | | | | | | |
| Skiing | 8 | | | | | | |
| Soccer (W) | 9 | | | | | | |
| Softball | 10 | | | | | | |
| Swimming/Diving | 11 | | | | | | |
| Tennis (M) | 12 | | | | | | |
| Tennis (W) | 13 | | | | | | |
| Track and Field | 4 | | | | | | |
| Volleyball | 15 | | | | | | |

**Figure 2:** Athlete coding

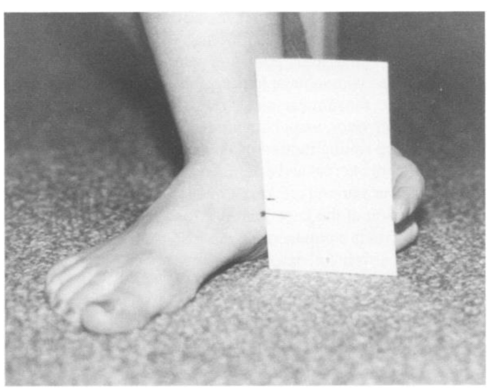

**Figure 3:** Navicular drop [15]

**Table 1**
**Descriptive Statistics**

| Sport | n athletes | n drop | Combined mean ±SD (mm) | n HP drop | HP mean ±SD (mm) | n control drop | n control mean ±SD (mm) |
|---|---|---|---|---|---|---|---|
| **Baseball** | 32 | 52 | 10.25±4.80 | 35 | 12.57±3.89 | 17 | 5.47±2.29 |
| **Men's Basketball** | 13 | 20 | 9.50±3.78 | 11 | 11.91±3.39 | 9 | 6.56±1.33 |
| **Women's Basketball** | 11 | 15 | 13.60±4.12 | 14 | 14.00±3.96 | 1 | 8.00 |
| **T&F/XC** | 21 | 33 | 8.64±3.31 | 13 | 11.69±3.09 | 20 | 6.65±1.35 |
| **Gymnastics** | 10 | 11 | 7.73±2.41 | 4 | 10.25±1.26 | 7 | 6.29±1.50 |
| **Soccer** | 15 | 24 | 10.503.04 | 17 | 11.94±2.28 | 7 | 7.00±1.15 |
| **Men's Tennis** | 5 | 9 | 8.00±1.87 | 3 | 10.33±0.58 | 6 | 6.83±0.75 |
| **Women's Tennis** | 5 | 8 | 8.13±3.91 | 2 | 13.50±3.54 | 6 | 6.33±1.86 |
| **Volleyball** | 13 | 20 | 8.05±4.58 | 10 | 11.50±3.27 | 10 | 4.60±2.67 |
| **Males** | 50 | 81 | 9.81±4.35 | 49 | 12.29±3.67* | 32 | 6.03±1.91* |
| **Females** | 76 | 111 | 9.48±4.00 | 60 | 12.23±3.16* | 51 | 6.24±1.87* |
| **Overall** | 125 | 192 | 9.62±4.14 | 109 | 12.26±3.38* | 83 | 6.16±1.88* |

*Denotes significant differences between the HP and control group means at p<.001

## RESULTS

A total of 141 potential subjects across nine sports were eligible for inclusion in the study based on availability of the athletes for data collection and interest of each supervisory athletic trainer. Of the 141 potential subjects, 125 met the inclusion criteria after completing the LBIQ and a total of 192 navicular drop values were recorded. Teams included were baseball (n athlete=32, n drop=52), men's basketball (n athlete=12, n drop=20), women's basketball (n athlete=11, n drop=15), cross country/track and field (n athlete=21, n drop=33), women's soccer (n athlete=15, n drop=24), men's tennis (n athlete=5, n drop=9) and women's tennis (n athlete=5, n drop=8), gymnastics (n athlete=10, n drop=11), and volleyball (n athlete=13, n drop=20).

The mean navicular drop overall (n=192) was 9.62mm (±4.14), and within the HP (n=109) group, the mean was 12.16mm (±3.38) compared to 6.16mm (±1.88) in the control group (n=83) (Figure 4). A two-way ANOVA was conducted to examine the effect of group and gender on the navicular drop. A statistically significant main effect for group, $F(2,186) = 207.42$, $p<0.001$ was identified, but there were no significant gender or gender by group interactions ($p\geq 0.05$). In an independent t-test, there was a significant difference between the means in both men and women when comparing HP and control groups at $p<.001$. After 10 months of tracking injury status within the study participants, there were no non-contact ACL tears recorded.

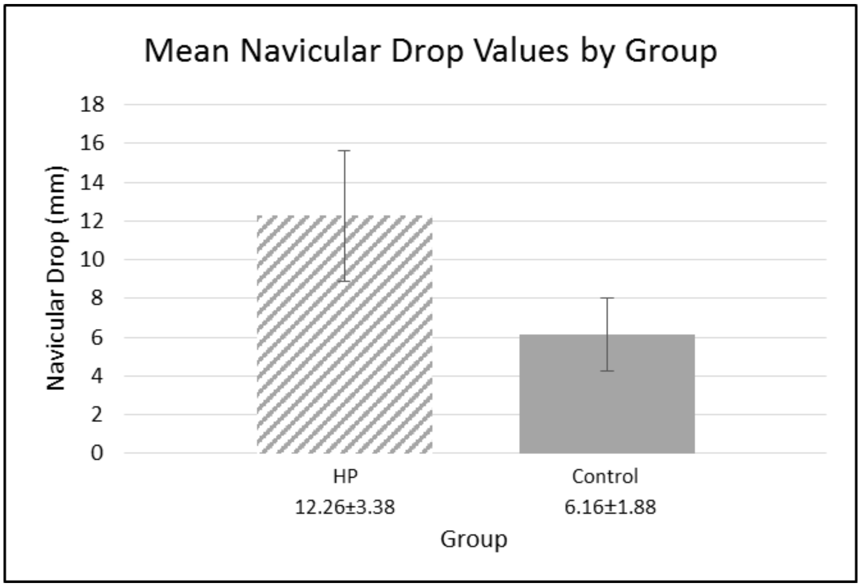


**Figure 4:** HP and control group navicular drop means with SD bars.

# DISCUSSION

The purpose of this study was to examine the relationship between non-contact ACL injuries and hyperpronation in an athletic population, to determine if hyperpronation leads to an increased risk of non-contact ACL injuries. Based on current literature, it was hypothesized that the hyperpronation (HP) group would sustain more non-contact ACL injuries than the control group due to the preloading effect that hyperpronation has on the ACL.[8,9,11,14] Previous studies comparing ACL injuries and hyperpronation have been cross sectional in nature, either comparing ACL injured subjects to matched controls or comparing non-injured to injured limbs within the same subject.[7,8,9,13,20,24] To date, this is the first attempted longitudinal study concerning the incidence of non-contact ACL injuries in a hyperpronated athletic population.

While hypothesized results were limited due to the lack of non-contact ACL tears within the participant population, there was some insight to be gained from the data collected. This was the largest study to date comparing navicular drop to non-contact ACL injuries with both the highest number of participants (n=125) and the highest number of navicular drop data collected (n=192). The current study also observed athletes from nine different sports which makes it unique as previous studies have recorded data from only one or two sports or sampled from the general population.[7,8,9,13,20,24] Because of the large amount of data in comparison to other studies, it was debatable as to whether the current data would show similar significant differences and trends to previous research. However, it was found that the current data did trend towards similarity from previous research. Of note, the mean navicular drop for the HP group was significantly different than the mean navicular drop for the control group by 6.10mm. If we see the HP group as the group with injury potential, as was the hypothesis, the significance between the means agrees with previous research that has found the same to be true.[7,8,9,20] This significance was also found between the HP and control groups when separated for gender, that is to say the HP and control group means were statistically significantly different whether combined or separated by gender into male or female subgroups. This is important as previous research has either not found a difference when separating for gender or did not attempt to compute one.[7,8,9,20,24] Within the HP and control groups, there were no significant differences between the means when separating for gender.

As can be seen in Table 2, the current study exhibits the largest number of subjects ever studied with respect to non-contact ACL tears and navicular drop measurement. This is important to note as the mean navicular drop scores in both the HP (12.36±3.38mm) and control (6.16±1.88mm) groups are similar when compared to results of the injured and control groups from the second largest study conducted by Beckett et al. (1992) (ACL injured 13.0±4.4mm, control 6.9±3.2mm). As can be seen in the Beckett et al. data, the standard deviations are quite large, most likely due to the small sample size. Even though Jenkins et al. (2007) used 89 healthy control subjects, his small number of ACL injured subjects makes the data less comparable. Additionally, his was among only two studies to not find a relationship between navicular drop and ACL injury, although he stated that he did find a trend towards significance in his data at p=.06.[24] Previous studies have such small sample sizes and typically observe injury in only one or two different sports and therefore, the data are easily biased. A wider range of sports and athletes are needed to create a population of data worth comparing pre-injury navicular drop data to. A more inclusive data set will give a vastly different, and more representative, look at the population in question.

While a prospective cohort study is not ideal for data collection and obtaining significant results, it is important to carry out. Smith et al. (1997), even though they did not find navicular drop to be a significant predictor of ACL injuries, cautioned that their study and previous studies assumed the uninjured leg is representative of an uninjured state and recommended further study, specifically, a prospective study so that the uninjured limb is not affected by the injured limb in the same subject. [13] Similarly, Moul et al. (1998) simply stated that “longitudinal data regarding these variables as reliable predictors are needed” (p. 121).[22] Woodford-Rogers et al. (1994) echoed these sentiments in their research by concluding that if the results that they and others have found to be significant are additionally substantiated by large prospective studies, then practitioners can start to use these anatomical factors as predictors for those at risk of ACL injuries through preparticipation screenings.[20] Although the current study was inconclusive, it is an important milestone in the study of predictive risk factors for ACL injury. As recent as 2013, studies were being published citing the same references from the mid-1990s to mid-2000s used in this study, most of which called for further prospective research and of which none have been completed to this author’s knowledge. Specifically Laible, Orrin, and Sherman (2013) in their discussion of Risk Factors and Prevention Strategies of Non-Contact Anterior Cruciate Ligament Injuries cited Beckett et al. (1992), Loudon et al. (1996), and Woodford-Rogers et al. (1994) with respect to discussing the role of navicular drop as a predisposing anatomical risk factor for non-contact ACL injuries.[8,9,20]

An indication for large prospective studies to be conducted is reliant on existing research that shows how gait, posture, and landing mechanics are changed after an ACL injury.[27, 29] These studies demonstrate the reasoning behind excluding subjects with any previous lower body fractures or surgeries in the current study. Goerger et al. (2015) studied the effect of previous ACL injury on lower extremity biomechanics of landing tasks and found that landing patterns were altered in such a way as to increase the risk of injury both to the previously injured limb and also the noninjured limb.[29] Knoll et al. (2004) found that normal gait patterns in ACL repaired subjects took a full 8 months to return to normal values when compared to normative data.[30] Referring back to Table 2, this is important to note as many of the injured subjects in previous research had undergone reconstructive surgery and yet there was no emphasis placed on the time of navicular drop measurement after they had received surgery.

In addition, the cyclical nature of sport demands a longer period of data collection to allow for a constant influx of new subjects into the study, thus increasing exposure rate and potentially injury rate. An example of this stems from unofficial data gathered by the researcher from the different athletic trainers associated with the sports teams used in this study. Unofficial data indicate as many as nine ACL injuries were recorded in the year prior to the current reporting period. Although some injuries occurred in sports not included in the current study, these athletes would not only be excluded from this study but from any study conducted in additional years based on their injury and subsequent repair. Ideally, following a population through their athletic careers from sophomore to seniors would allow for more adequate selection. As per the Hootman et al. (2007) study, injury risk increases with the number of athlete exposures (an exposure is defined as one practice or one game) and following a population throughout their athletic career would allow for significantly more athlete exposures to occur.[2] Data by Hootman et al. (2007) show that ACL injury rates, defined as injuries per 1000 athlete exposures, range between 0.02 in men's baseball to 0.33 in women's gymnastics.[2] Arendt et al. (1999), looking at men's and women's soccer and basketball specifically, found ACL injury rates (again per 1000 athlete exposures) ranging from 0.07 in men's basketball to 0.33 in women's soccer.[3] Both of these studies look at data longitudinally over a period of 10 to 15 years using the NCAA ISS where the database was thousands of athlete exposures. Over the course of a single season, one team may not reach 1000 exposures and as reported injury rates are below 1.00, a single season may not be enough exposure to produce injury, as was the case in the current study. In short, the role of navicular drop needs to be addressed prospectively to determine if it is indeed a factor in non-contact ACL injuries.

Only nine out of a potential fifteen Division I NCAA teams participated in the study, with football being the most absent of the teams. With a roster averaging between 85 and 115 student athletes, this lack of participation nearly halved the expected participation and number of subjects. The absence of teams from the current study was mostly due to time constraints of the teams and their athletic trainers, but also due in part to an uncertainty involving the relationship between navicular drop and non-contact ACL injuries. Some of the athletic trainers approached regarding the study were wary of committing their student athletes to further testing and evaluation either at preparticipation physicals or preseason training. Additional reporting periods as well as educational sessions demonstrating the relationship between hyperpronation and preloading of the ACL could lessen this anxiety and lead to a more standardized approach of measurement among the teams. Attempting to include all NCAA Division I student athletes at an institution could not only increase the sample size but also greatly increase the number of athlete exposures to injury within any given reporting period.

### *Limitations*

Intrinsic factors such as other biomechanical intrinsic factors, hormonal factors, and neuromuscular factors have been overlooked in the current study as the focus of the study was on the anatomical factor of navicular drop. While the reader may think this is extremely limiting, comparative research has not evaluated these additional intrinsic factors in their research, that is to say the majority of previous research comparing navicular drop values to ACL injury risk has only compared navicular drop values and has not taken into account additional factors.[7,8,9,13,20,24] While Louden et al. (1996) observed static alignment of the lower extremity, they deemed navicular drop and subtalar joint alignment to be the most predisposing and significant factors in predicting ACL injury from static posture.[9] Jenkins et al. (2007) came to the same conclusion.[24]

Extrinsic or environmental factors were not overlooked though they were excluded from this study for similar reasons. Research has shown that the role of environmental factors, such as shoe type, cleat length, shoe-surface interaction, and playing surface, are highly inconclusive and therefore were not included in this study.[4,5,6,23] Orthotic use is another extrinsic factor not examined. The use of orthotics is still widely debated and research has revealed varying results with respect to controlling foot motion as well as altering lower leg kinematics.[16,31] Carcia et al. (2006) found that in female athletes with pes planus feet, a rigid orthotic did not alter transverse plane lower body kinematics in those with a navicular drop greater than eight millimeters.[31] As 9mm is the accepted cutoff for hyperpronation, athletes with a navicular drop greater than or equal to 9mm using this orthotic would likely not see a change in their lower body kinematics either. Carcia et al. (2006) concluded that further biomechanical and neuromuscular factors were likely responsible in controlling navicular drop in these athletes but recommend further research in this area.[31] In a study on walking with and without a foot orthotic, Chen et al. (2010) found mixed results as there was some interaction between the foot and ankle joint with the orthotic but no result on the knee or hip.[16]

Subject size and stature can be seen as an intrinsic limitation within this study, and while it is unchangeable, it should be discussed. The classification of hyperpronation uses a standard cut off of 9mm; in excessively small or large statured subjects, this may not relate the position of the navicular tuberosity as it should.[5,7,15,24] Louden et al. (1996) implemented ranges of navicular drop values to classify individuals into either low (<6mm), normal (6-9mm), or high (>9mm) navicular drop groups.[9] Bennett (2003) and Woodford-Rogers et al. (1994) both mention subject stature as a potential limitation as they did not exclude those obese or small subjects, gymnasts in the case of Woodford-Rogers.[10,20] While some previous studies record demographic data and others match subjects for age, height, or weight, the analysis run on the navicular drop data does not take into account subject size and it is often mentioned later as an afterthought or not included at all.[7,8,9,14,18,20,24] For this reason, demographic data were not collected for the participants in this study. In future studies, it may be beneficial to include such demographic data such as age, height, and weight so that navicular drop could be compared to subject size. However, as this comparison has not been conducted before, this information would not relate directly to previous research. Additionally, the sample size used in this study, and presumably in future longitudinal studies, should be large enough to take the bias away from using various sized athletes and obtaining a wide range of navicular drop values.

**Table 2**
***Reported Navicular Drop Values***

| Investigator | Group | n | Mean ±SD Navicular Drop (mm) | Injury Mechanism | ACL Repaired |
|---|---|---|---|---|---|
| Allen et al. (2000) | Control | 18 | 8.1 ±2.8 | | |
| | ACL Injured | 12 m, 6 f | 10.5 ±4.0 | Various | 16 |
| Beckett et al. (1992) | Control | 39 m, 11 f | 6.9 ±3.2 | | |
| | ACL Injured | 39 m, 11 f | 13.0 ±4.4 | Various | Some (undefined) |
| Jenkins et al. (2007) | Control | 89 mixed | 10.0 ±4.4 | | |
| | ACL Injured | 2 m, 14 f | 10.6 ±4.3 | | All |
| Loudon et al. (1996) | Control | 20 f | * | Non-contact | |
| | ACL injured | 20 f | * | | 8 |
| Smith et al. (1997) | Control | 7 m, 7 f | 6.2 ±2.6 | | |
| | ACL Injured | 7 m, 7 f | 6.3 ±3.1 | Non-contact | All |
| Woodford-Rogers et al. (1994) | Control | 14 m | 5.9 ±4.2 | | |
| | ACL Injured | 14 m | 8.4 ±4.2 | Various | Some (undefined) |
| | Control | 8 f | 3.0 ±1.1 | | |
| | ACL Injured | 8 f | 5.0 ± 2.5 | Non-Contact | Some (undefined) |
| Arduini et al. (2016) | Control | 32 m | 6.03 ±1.91[₸] | | |
| | HP | 49 m | 12.29 ±3.67[₸] | | |
| | Control | 51 f | 6.24 ±1.87[₸] | | |
| | HP | 60 f | 12.23 ±3.16[₸] | | |
| | Control | 83 mixed | 6.16 ±1.87[₸] | | |
| | HP | 109 mixed | 12.26 ±3.38[₸] | | |

*Mean values not reported, groups of low (less than 6mm), normal (6-9mm), and high (greater than 9mm) were used. 15 ACL injured subjects had navicular drops greater than 9mm compared to 6 in the uninjured (control) group.

₸ Denotes statistically significant difference between the means

# CONCLUSIONS

ACL injuries are common in both the general and athletic population. In particular, athletic populations are at risk for an ACL injury due to the non-contact mechanism of injury typical in ACL injuries. Usually, this involves landing from a jump, pivoting, or changing direction, movements that are constantly being performed during sport. Navicular drop, as it relates to pronation of the foot, has been found to be a significant factor in previous cross-sectional studies demonstrating that hyperpronation causes a preloading effect on the ACL due to the tibia being forced into prolonged internal rotation.

As there has not been a longitudinal study performed, the goal of this study was to investigate the effect of navicular drop on the incidence of non-contact ACL tears prospectively in a hyperpronating athletic population. In the prospective design, each navicular drop was considered as its own case and followed throughout a competitive season, a course of approximately 10 months. It was hypothesized that there would be more non-contact ACL injuries within the HP group than in the control group.

While no non-contact ACL injuries were noted during the injury tracking timeframe, navicular drop data in the HP group are similar to values found in previous research. In addition, the differences in navicular drop were statistically significantly different between the HP and control groups both overall and when compared by gender. This agrees with previously completed research. As the large navicular drop in the current HP group was similar to that in previously ACL injured participants, one can postulate that the current HP group would suffer ACL injuries if given the chance, that is to say if given additional exposure to injury. In the year prior to data collection, approximately nine non-contact ACL injuries were recorded and these subjects were excluded from additional testing, lowering the pool of navicular drops from which to measure and lowering the overall number of athlete exposures. This is the cyclical nature of sport and injury and the only way to help control for it is with further prospective studies. Clinically relevant is the time lost to rehabilitation, typically the remainder of the season, and the cost to the university associated with non-contact ACL injuries within an athletic population. If hyperpronation can be identified through further research as a predictor of non-contact ACL injuries, preventative steps can be taken to attempt to limit the effect of hyperpronation on the kinematics of the knee. However, continued study over a longer injury tracking timeframe with additional athletes needs to be conducted to determine if hyperpronation can be classified as a predictor variable for non-contact ACL injuries.

# APPENDIX

## LOWER BODY INJURY QUESTIONNAIRE (LBIQ)

Name: ______________________________
Subject ID #: _________________________ (to be filled out by examiner)

Please fill out the following questionnaire to the best of your knowledge. If you are unsure of the amount of time lost to an injury please err of the side of caution and increase the number of days assumed lost by 10%.

1) Have you ever suffered a lower body injury? YES NO

Injury includes, but is not limited too; fracture, ligament or capsule sprain, muscle strain, contusion (bruise), infection, meniscal or disc tear or hernia.

2) If you answered YES to the above question please list all lower body injuries sustained below and indicate the time lost to that specific injury.

Time lost is defined as the number of days you were unable to participate in your sport at the level in which you were playing when you sustained the injury.

For example, if you were a varsity soccer player and were unable to practice or play varsity soccer with that team for 10 days your time lost would be 10 days, even if you were able to participate in soccer with another groups or team.

| | Injury (please indicate the date of injury) | Time Lost | Examiners Only | |
|---|---|---|---|---|
| | | | DOI | Time Lost |
| 1 | | | A / D | A / D |
| 2 | | | A / D | A / D |
| 3 | | | A / D | A / D |
| 4 | | | A / D | A / D |
| 5 | | | A / D | A / D |
| 6 | | | A / D | A / D |
| 7 | | | A / D | A / D |
| 8 | | | A / D | A / D |
| 9 | | | A / D | A / D |
| 10 | | | A / D | A / D |

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